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# High-Tc superconductivity in undoped ThFeAsN

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## Abstract

© 2017 The Author(s). Unlike the widely studied ReFeAsO series, the newly discovered iron-based superconductor ThFeAsN exhibits a remarkably high critical temperature of 30 K, without chemical doping or external pressure. Here we investigate in detail its magnetic and superconducting properties via muon-spin rotation/relaxation and nuclear magnetic resonance techniques and show that ThFeAsN exhibits strong magnetic fluctuations, suppressed below ~35 K, but no magnetic order. This contrasts strongly with the ReFeAsO series, where stoichiometric parent materials order antiferromagnetically and superconductivity appears only upon doping. The ThFeAsN case indicates that Fermi-surface modifications due to structural distortions and correlation effects are as important as doping in inducing superconductivity. The direct competition between antiferromagnetism and superconductivity, which in ThFeAsN (as in LiFeAs) occurs at already zero doping, may indicate a significant deviation of the s-wave superconducting gap in this compound from the standard s ± scenario.

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## References

[1] Kamihara, Y. et al. Iron-based layered superconductor: LaOFeP. J. Am. Chem. Soc. 128, 10012-10013 (2006).

[2] Tapp, J. H. et al. LiFeAs: an intrinsic FeAs-based superconductor with T = 18 K. Phys. Rev. B 78, 060505(R) (2008).

[3] Hsu, F.-C. et al. Superconductivity in the PbO-type structure α-FeSe. Proc. Natl Acad. Sci. 105, 14262 (2008).

[4] Kamihara, Y., Watanabe, T., Hirano, M. & Hosono, H. Iron-based layered superconductor La[O F]FeAs (x = 0.05-0.12) with T = 26 K. J. Am. Chem. Soc. 130, 3296-3297 (2008).

[5] Wen, H.-H. Developments and perspectives of iron-based hightemperature superconductors. Adv. Mater. 20, 3764-3769 (2008).

[6] Sadovskii, M. V. High-temperature superconductivity in iron-based layered iron compounds. Phys. Usp. 51, 1201 (2008).

[7] Paglione, J. & Greene, R. L. High-temperature superconductivity in iron-based materials. Nat. Phys. 6, 645-658 (2010).

[8] Johnston, D. C. The puzzle of high temperature superconductivity in layered iron pnictides and chalcogenides. Adv. Phys. 59, 803-1061 (2010).

[9] Si, Q., Yu, R. & Abrahams, E. High-temperature superconductivity in iron pnictides and chalcogenides. Nat. Rev. Mater. 1, 16017 (2016).

[10] Muraba, Y., Matsuishi, S. & Hosono, H. La-substituted CaFeAsH superconductor with T = 47 K. J. Phys. Soc. Jpn. 83, 033705 (2014).

[11] Muraba, Y., Iimura, S., Matsuishi, S. & Hosono, H. Hydrogensubstituted superconductors SmFeAsO H misidentified as oxygen-deficient SmFeAsO. Inorg. Chem. 54, 11567-11573 (2015).

[12] Mazin, I. I., Singh, D. J., Johannes, M. D. & Du, M. H. Unconventional superconductivity with a sign reversal in the order parameter of LaFeAsO F. Phys. Rev. Lett. 101, 057003 (2008).

[13] Chubukov, A. V., Efremov, D. V. & Eremin, I. Magnetism, superconductivity, and pairing symmetry in iron-based superconductors. Phys. Rev. B 78, 134512 (2008).

[14] Kuroki, K., Usui, H., Onari, S., Arita, R. & Aoki, H. Pnictogen height as a possible switch between high-T nodeless and low-T nodal pairings in the iron-based superconductors. Phys. Rev. B 79, 224511 (2009).

[15] Ahn, F. et al. Superconductivity from repulsion in lifeas: novel s-wave symmetry and potential time-reversal symmetry breaking. Phys. Rev. B 89, 144513 (2014).

[16] Sprau, P. O. et al. Discovery of orbital-selective cooper pairing in FeSe. Preprint at http://arxiv.org/abs/1611.02134 (2016).

[17] Nourafkan, R., Kotliar, G. & Tremblay, A.-M. S. Correlationenhanced odd-parity interorbital singlet pairing in the iron-pnictide superconductor LiFeAs. Phys. Rev. Lett. 117, 137001 (2016).

[18] Wang, C. et al. A new ZrCuSiAs-type superconductor: ThFeAsN. J. Am. Chem. Soc. 138, 2170 (2016).

[19] Sanna, S. et al. Intrinsic ferromagnetic impurity phases in SmFeAsO F detected by μSR. J. Supercond. Nov. Magn. 22, 585-588 (2009).

[20] Lamura, G. et al. Crossover between magnetism and superconductivity in LaFeAsO with low Hdoping level. J. Phys. Condens. Matter 26, 295701 (2014).

[21] Walstedt, R. E. & Walker, L. R. Nuclear-resonance line shapes due to magnetic impurities in metals. Phys. Rev. B 9, 4857-4867 (1974).

[22] Khasanov, R. et al. Muon spin rotation studies of SmFeAsO and NdFeAsO superconductors. Phys. Rev. B 78, 092506 (2008).

[23] Sanna, S. et al. Magnetic-superconducting phase boundary of SmFeAsO F studied via muon spin rotation: unified behavior in a pnictide family. Phys. Rev. B 80, 052503 (2009).

[24] Albedah, M. A. et al. Absence of the stripe antiferromagnetic order in the new 30 K superconductor ThFeAsN. J. Alloys Compd. 695, 1128-1136 (2017).

[25] Luetkens, H. et al. The electronic phase diagram of the LaO F FeAs superconductor. Nat. Mater. 8, 305-309 (2009).

[26] Sanna, S. et al. Nanoscopic coexistence of magnetic and superconducting states within the FeAs layers of CeFeAsO F. Phys. Rev. B 82, 060508 (2010).

[27] Shiroka, T. et al. Long- to short-range magnetic order in fluorine-doped Ce-FeAsO. Phys. Rev. B 84, 195123 (2011).

[28] Brandt, E. H. Properties of the ideal Ginzburg-Landau vortex lattice. Phys. Rev. B 68, 054506 (2003).

[29] Brandt, E. H. Muon spin rotation and the vortex lattice in superconductors. Physica B 404, 695-699 (2009).

[30] Sonier, J. E. Muon spin rotation studies of electronic excitations and magnetism in the vortex cores of superconductors. Rep. Prog. Phys. 70, 1717 (2007).

[31] Barford, W. & Gunn, J. M. F. The theory of the measurement of the London penetration depth in uniaxial type II superconductors by muon spin rotation. Physica C 156, 515-522 (1988).

[32] Fesenko, V. I., Gorbunov, V. N. & Smilga, V. P. Analytical properties of muon polarization spectra in type-II superconductors and experimental data interpretation for mono- and polycrystalline HTSCs. Physica C 176, 551-558 (1991).

[33] Wang, G. & Shi, X. Electronic structure and magnetism of ThFeAsN. Europhys. Lett. 113, 67006 (2016).

[34] Singh, D. J. ThFeAsN in relation to other iron-based superconductors. J. Alloys Compd. 687, 786-789 (2016).

[35] Uemura, Y. J. et al. Basic similarities among cuprate, bismuthate, organic, Chevrel-phase, and heavy-fermion superconductors shown by penetration-depth measurements. Phys. Rev. Lett. 66, 2665-2668 (1991).

[36] Grafe, H.-J. et al. As NMR studies of superconducting LaFeAsOF. Phys. Rev. Lett. 101, 047003 (2008).

[37] Nakai, Y. et al. An NMR study on the F-doping evolution of the iron oxypnictide LaFeAs(O F). New. J Phys. 11, 045004 (2009).

[38] Slichter, C. P. Principles of Magnetic Resonance 3rd edn (Springer Verlag, 1992).

[39] Kimber, S. A. J. et al. Similarities between structural distortions under pressure and chemical doping in superconducting BaFeAs. Nat. Mater. 8, 471-475 (2009).

[40] Blundell, S. J. Spin-polarized muons in condensed matter physics. Contemp. Physics 40, 175-192 (1999).

[41] Yaouanc, A. & de Réotier, P. D. Muon Spin Rotation, Relaxation, and Resonance: Applications to Condensed Matter (Oxford University Press, 2011).

[42] Sato, T. et al. Superconducting gap and pseudogap in iron-based layered superconductor La(O F)FeAs. J. Phys. Soc. Jpn. 77, 063708 (2008).

[43] Buckel, W. & Kleiner, R. Superconductivity. Fundamentals and Applications 2nd edn, Ch. 4 (Wiley-VCH, 2004).